Ontario

Ministry of Transportation and Communications
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Highway Engineering Division

Engineering Materials Office

EM-63

Provincial Highways

Hot-Mix Paving Cessation Temperature

Precis

This report documents a study carried out to determine if:

(a) surface temperature could replace air temperature as the controlling factor for cold weather paving cessation.

(b) the current low temperature limits could be relaxed.

The report includes a review of the existing literature, a summary of the field work, an evaluation of surface thermometers available, a comparison of actual and theoretical mat temperatures and a method which can be used as a guide to determine whether a contractor could pave under marginal weather conditions.

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1. Introduction and background

In May 1981, during discussion with the Ontario Road Builder's Association on the revisions to Form 310, MTC indicated that a study would be undertaken to determine whether the present fall paving termination conditions could be altered or removed.

During the Summer and Fall of 1981 the following work was carried out:

- Review of existing literature.
- Field trials to measure the cooling rate of an asphalt mat immediately after paving.
- Field work to measure the air temperature/surface temperature relationship.
- Field tests to determine the suitability of various inexpensive (less then $50.00) surface thermometers used to measure the surface temperature of asphalt pavement or of granular base (digital and infrared thermometers were not reviewed because of their cost of $500-2500).
- Comparison of the field results with theoretical curves.
- Extrapolation of theoretical curves to determine if present specifications should be altered.

From the above it was found that: because of the difficulties in reading surface temperatures, and the similarities between surface temperature and air temperature near the pavement surface, it would not be practical to base the paving cessation criteria on surface temperature.

Further, it was found that, under typical fall paving conditions, the middle of the mat cooled below 80°C before rolling was completed. The bottom of the mat cooled on contact with the base and never reached a high enough temperature to permit adequate compaction. Therefore, it is not advisable to remove or to lower the present restrictions.

2. Cooling rate of the mat

2.1 Purpose

The purpose of this component of the project was to determine if the present temperatures governing paving cessation could be lowered. The work consisted of field work to measure the temperature of the mat as it cooled after laydown, a literature search and a comparison of field measurements and those predicted in the literature to determine if the temperature restrictions could be lowered.

2.2 Field Work

The field work was performed in the fall of 1981 by Mr. J. Pretty of the Bituminous Evaluation Laboratory.

Five contracts were visited: Contract 80-51, Hwy. 60; Contract 80-55, Hwy. 401; Contract 81-20, Hwy. 5; and Contract 81-48, Hwy. 406; and Contract 80-04, E.C. Row Expressway. Due to field test problems, insufficient data was collected on Contract 81-48. At each contract, sections of roadway were selected and the equipment and instruments necessary to take the various readings were set up prior to paving. The weather conditions and contract details were recorded and once the paver approached the test site recording of the following information began:

- laydown temperature. This reading represents the temperature of the mix in the hopper of the paver. It was measured with a temperature probe attached to a digital thermometer.
- temperature of the base, middle and surface of the mat.
- surface temperature of the shoulder rounding. (These readings were used to monitor the temperature of the granular base).
- air temperature, measured on the anemometer stand (about 1 m above the surface).
- wind speed. The wind speed was measured with an anemometer installed on the side of the road. The sending unit was located approximately 1 m above the surface.

All the above temperatures, except laydown temperatures, were measured with thermocouples attached to a digital thermometer.

The mat temperatures were recorded every 2 minutes during the first 20 to 25 minutes after laydown, when the temperature dropped rapidly, and at 5 minute intervals after that. The interval time was altered as necessary whenever instruments or recording problems were encountered. Shoulder rounding temperature, air temperature and wind speed were measured less frequently.

Field notes are included in Appendix A, a description of the equipment used is included in Appendix B, and mat temperatures of selected tests are shown in figures 1 to 8.

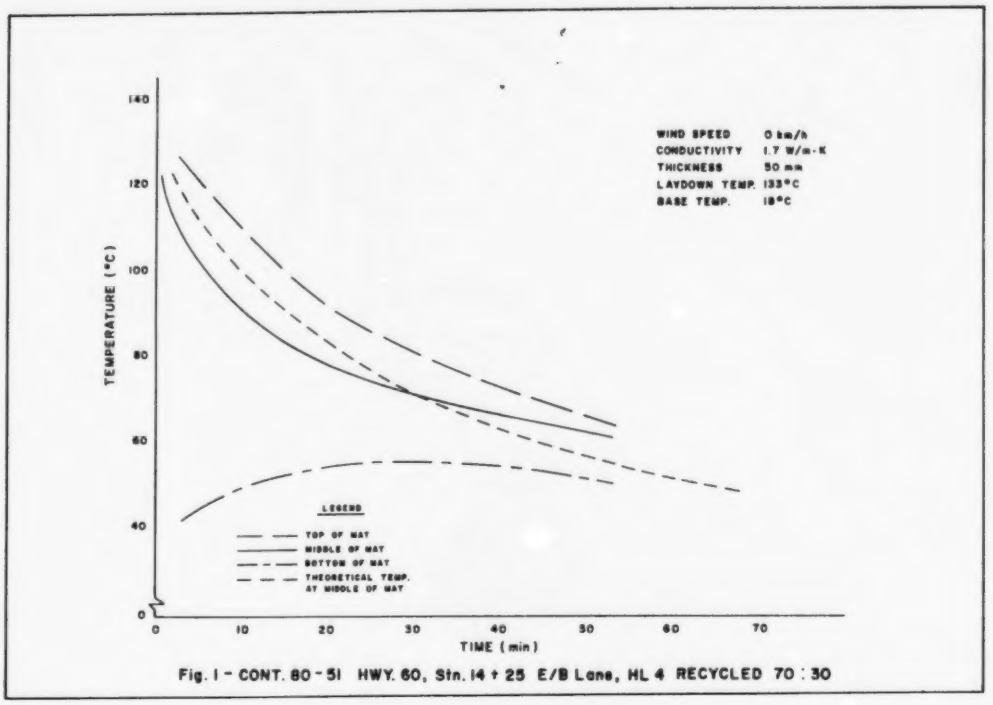

Fig. 1 - CONT. 80 - 51 HWY. 60, Stn. 14 + 25 E/B Lane, HL 4 RECYCLED 70 : 30

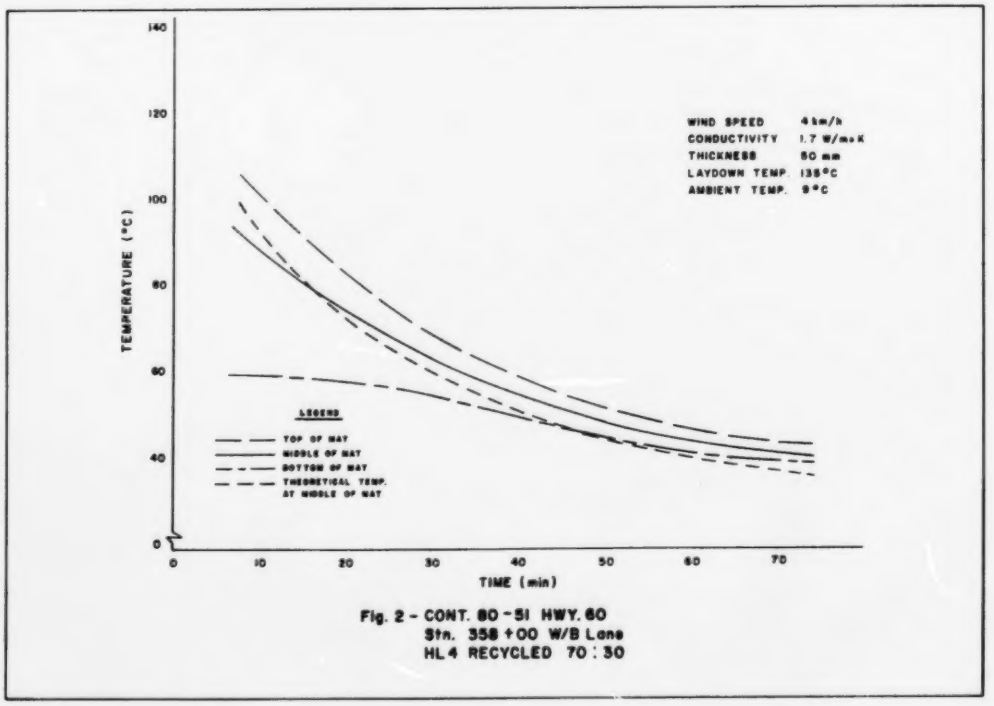

Fig. 2 - CONT. 80 - 51 HWY. 60
Stn. 358 + 00 W/B Lane
HL 4 RECYCLED 70 : 30

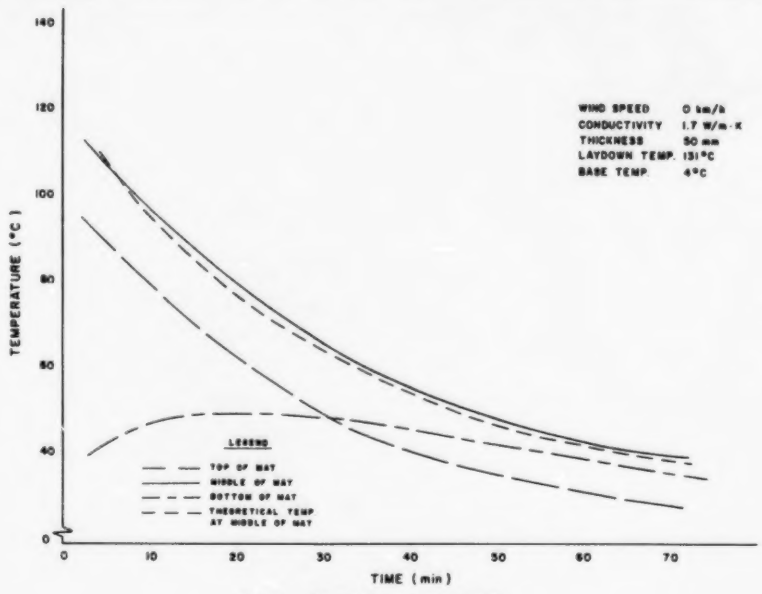

Fig. 3 - CONT. 80 - 51 HWY. 60
Stn. 376 + 00 E/B
HL 4 RECYCLED 70 : 30

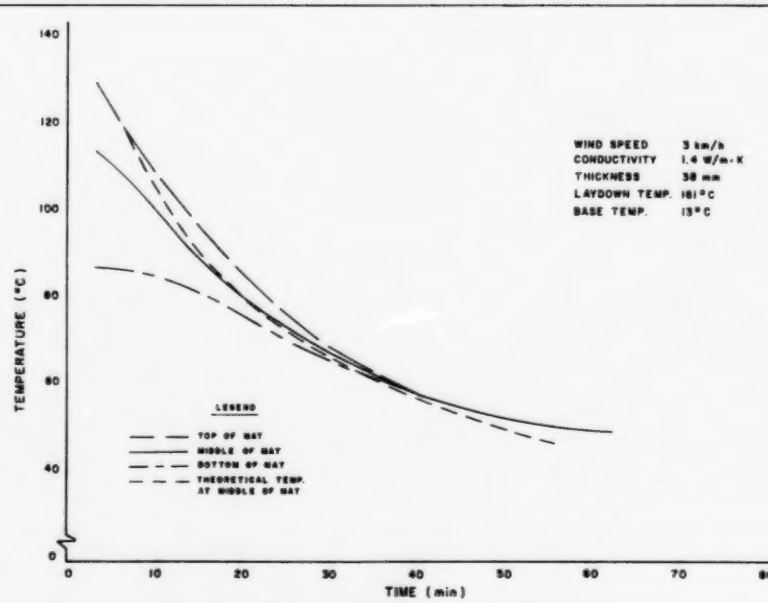

Fig. 4 - CONT. 80 - 55 HWY. 401
Stn. 249 + 45 Shoulder
HL 4

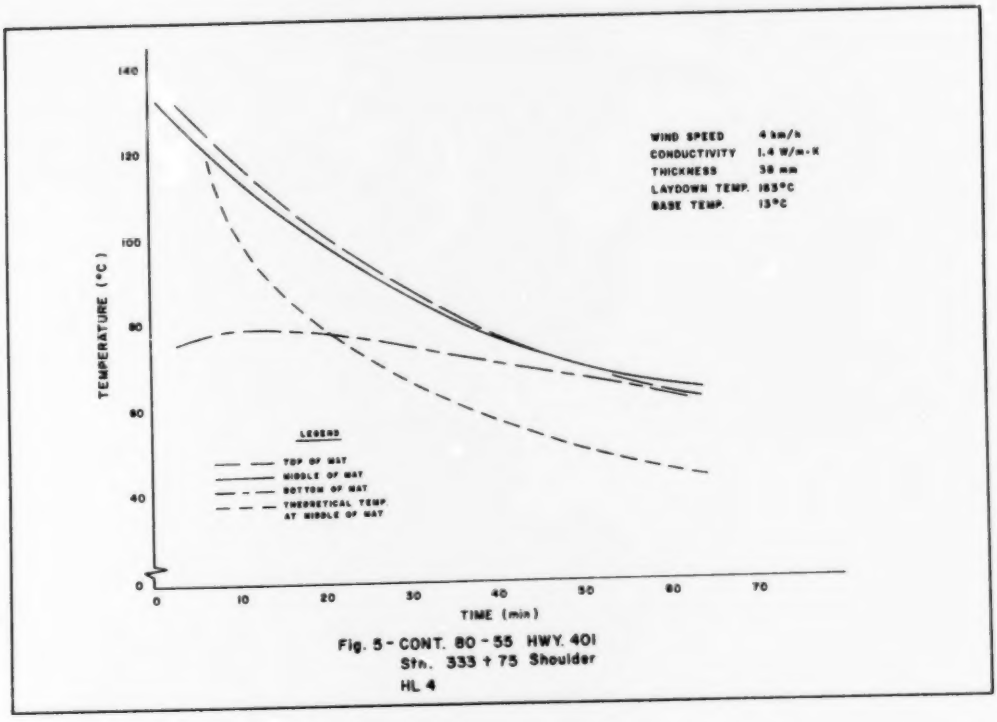

Fig. 5 - CONT. 80 - 55 HWY. 401
Stn. 333 + 75 Shoulder
HL 4

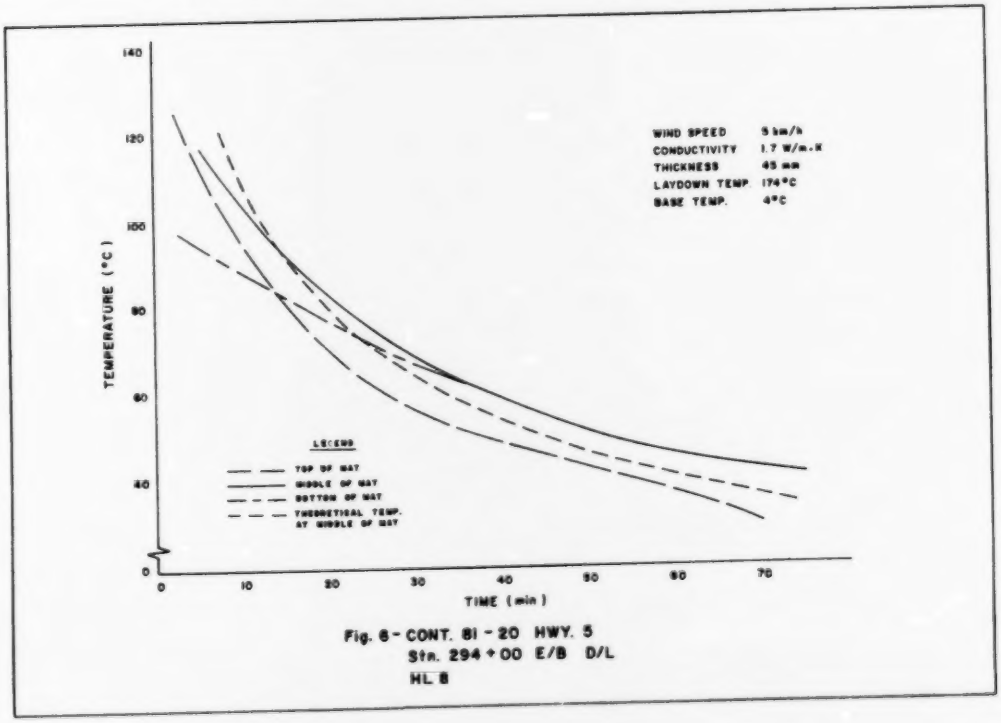

Fig. 6 - CONT. 81 - 20 HWY. 5
Stn. 294 + 00 E/B D/L
HL 8

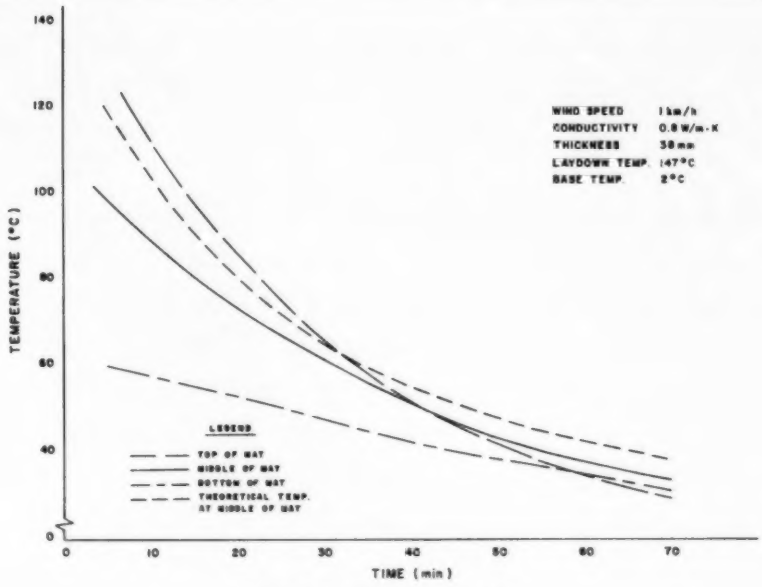

Fig. 7 - CONT. 80-04 E.C. ROW
Stn. 210 +00 E/B D/L
DFC (Steel Slag)

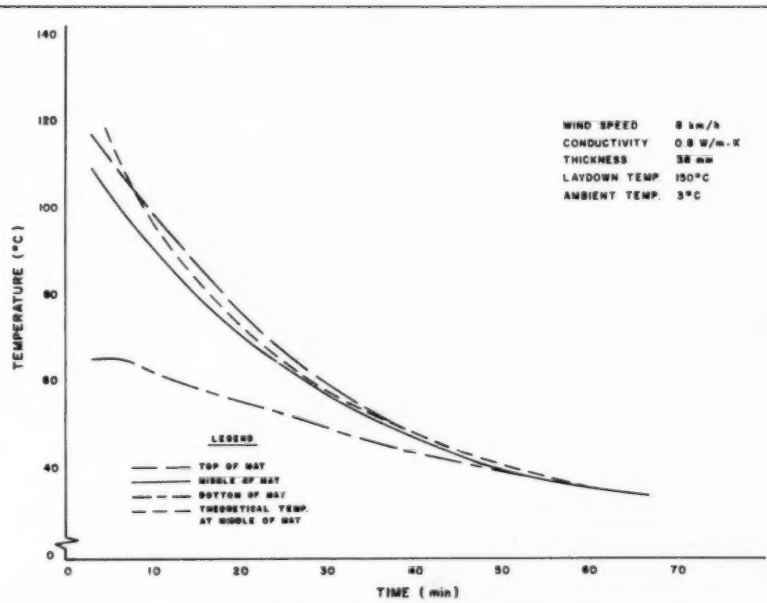

Fig. 8 - CONT. 80-04 E.C. ROW EXP.
HURON CHURCH Ramp
DFC - Slag

2.3 Observations

During the part of the study dedicated to the measurement of the cooling rate of the mat and to the measurement of the air temperature/base temperature relationship, the following observations were made:

- the contractor did not alter his normal paving procedures because of the experiment.
- the weather conditions were suitable for paving (except the three cases outlined below).
- the contractors met the temperature requirements of MTC Form 310 in all but three cases:
  - Contract 81-20, Hwy. 5. On 81 11 09, an intermediate binder was laid when the temperature was 4°C (7°C min. required).
  - Contract 80-04, E. C. Row Expressway. On 81 11 30 and 81 12 02 surface courses were laid when the temperature was 2°C and 3°C respectively (7°C min. required).
- the temperature of the mix usually dropped by 5 to 10 celsius degrees as it passed through the paver.
- the temperature of the mat usually was highest on the top surface and lowest at the bottom of the mat.
- the temperature at the bottom of the mat was seldom above 80°C, generally recognized as being the lowest temperature at which compaction can take place.
- surface temperature was difficult to measure with thermocouples. It was difficult to get intimate contact between the thermocouple and the pavement, especially with the displacement of wires and mix caused by the rollers.
- the roller operator often waited too long before starting to roll the pavement. The elapsed time between laydown and the first pass of the breakdown roller ranged between 2 and 14 minutes ($\bar{x}$ = 6 min, σ = 4 min).
- the total rolling period varied from 10 to 62 minutes ($\bar{x}$ = 37 min, σ = 18 min).
- the temperature of the mat at completion of rolling ranged from 37°C to 107°C ($\bar{x}$ = 63°C, σ = 2°C)

- the paving operation was not smooth and continuous. The contractors did not seem to be prepared for fall paving since the operation was often interrupted by frequent breakdowns, irregular deliveries of hot mix, insufficient grade prepared ahead of the paver etc...

2.4 Literature Search

Much has been written about the cooling rate of hot mix after laydown and the time available for adequate compaction of the mix. The literature identifies the following factors as having the greatest effect on the cooling rate of the mat:

- thickness of the mat
- laydown temperature of the mix
- temperature of the underlying base
- wind speed
- conductivity of the mix (a factor which is very difficult to measure)

Other factors such as insolation (effect of sunshine), cooling due to evaporation of water and emission or absorption of radiation are considered to be minor but measurable factors.

The major contributors to the literature on the topic are Messers. P. F. Dickson and J. S. Corlew.

These two researchers identified the factors mentioned above and then developed a mathematical model which predicted, among other things, how rapidly a particular mix would cool. Other researchers have modified or refined the Dickson and Corlew findings and applied them to their particular situations.

The model, or mathematical expression, used in this study to predict the cooling rate of a newly laid mat was developed by E. J. Dickinson of the Australian Road Research Board.

The mathematical expression is:

$$tc = Z \frac{X_1^2 (\theta m - \theta c)}{(\theta c - \theta s)} \qquad (1)$$

where tc= time for mat to cool to temperature θc (min.)

$Z = 0.0252 - 0.00061U + 0.000011U^2 - 0.0056k - 0.000103X_1$

X_1= thickness of compacted layer (mm)

θm= mix temperature at laydown (^oC)

θc= compaction cessation temperature (^oC)

θs= base temperature * (^oC)

U= wind speed (km/h)

k = conductivity of mat (W/m.K)

*= equal to air temperature (see section 3.5)

The expression assumes that the weather is clear and cool with a wind of 10 to 40 km/h. The value of k would not normally be known but can be assigned values ranging from 0.8 to 1.7 W/m.K.

Figures 1 to 8, which show the actual mat temperatures described earlier, also show the theoretical mid mat temperature predicted by the Dickinson model.

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(1) The Cooling of Asphalt Layers During the Compaction Operation, E. J. Dickinson, Australian Road Research Conference Proceedings Vol.3, no. 4.

Figures 9 to 13, derived from Dickinson's formula, show the effect each factor has on the cooling rate of a hot mix mat. The standard conditions assumed for this exercise are:

thickness of lift	=	40 mm
base temperature	=	10°C
laydown temperature	=	140°C
wind speed	=	10 Km/h
conductivity	=	1.2 W/m.K

2.5 Discussion

Compaction of bituminous mixtures is affected by many factors such as: composition of the mix, lift thickness, viscosity of the asphalt cement, equipment and compactive effort. Of these factors, compactive effort is the most variable of the controllable factors. It depends on production rate, number of rollers, rolling technique and the time available for compaction. Time available for compaction is probably the most critical factor during fall paving because of the rapid cooling of the hot mix.

Figures 1 to 8 show that the bottom of the hot mix cools as soon as it touches the underlying base. As heat flows from the mat to the base, the temperature at the interface rises but seldom reaches 80°C before it starts to drop again. The temperature at mid mat drops continuously after laydown and often drops below 80°C before rolling is completed.

The above observations indicate that typical MTC pavements (40 mm dense graded mix) are not adequately compacted when laid under fall conditions. Figure 14, based on the Dickinson formula described earlier, shows that a hot mix pavement 40 mm thick laid at 140°C on pavement at 10°C in very light wind (5 Km/h) would cool to 80°C in about 13 minutes (this temperature applies to mid mat temperature).

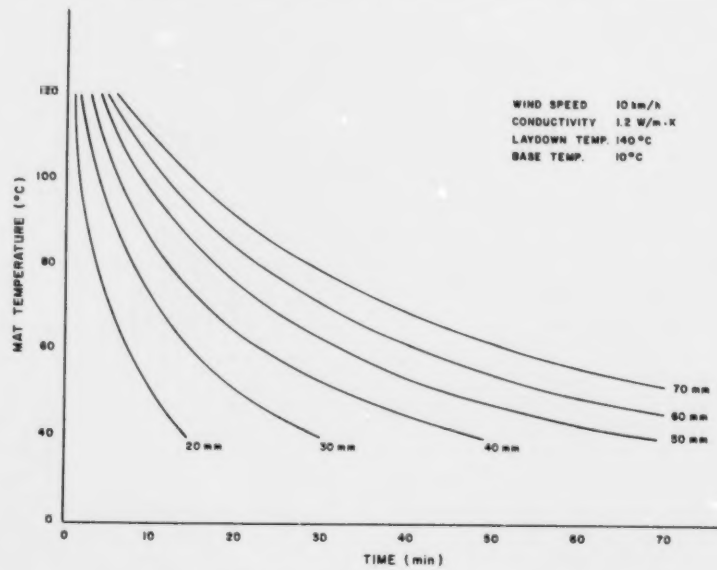

Fig. 9 - EFFECT OF LAYER THICKNESS ON COOLING RATE

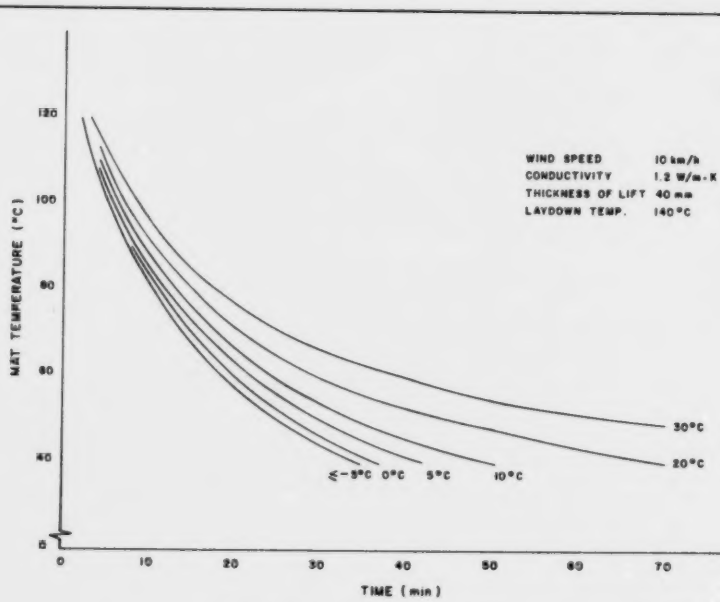

Fig. 10 - EFFECT OF BASE TEMPERATURE ON COOLING RATE

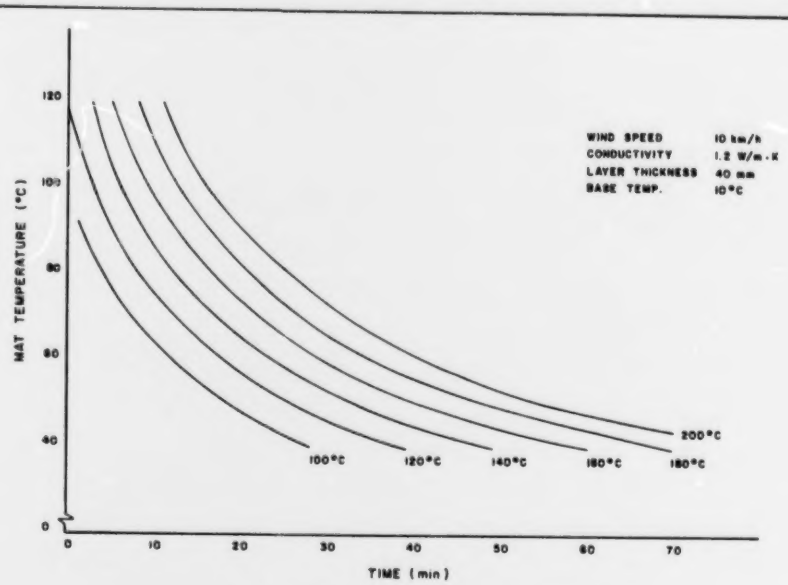

Fig. 11 - EFFECT OF LAYDOWN TEMPERATURE ON COOLING RATE

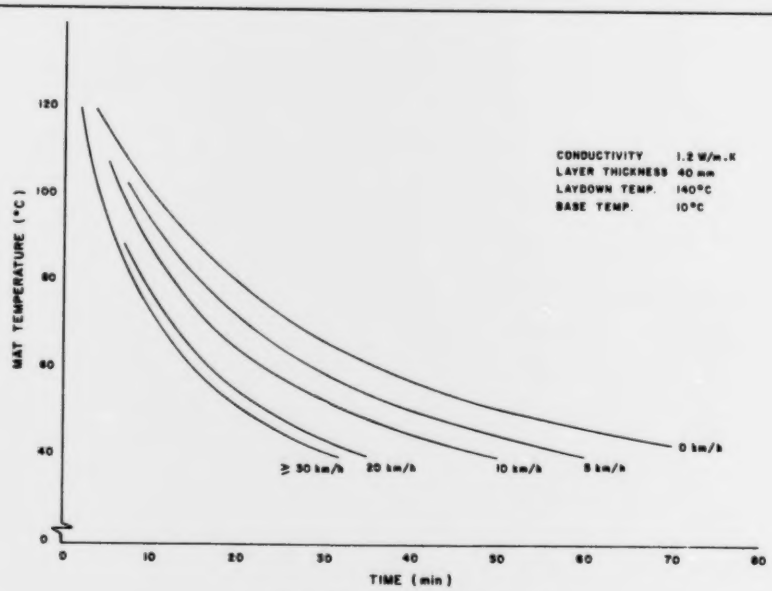

Fig. 12 - EFFECT OF WIND SPEED ON COOLING RATE

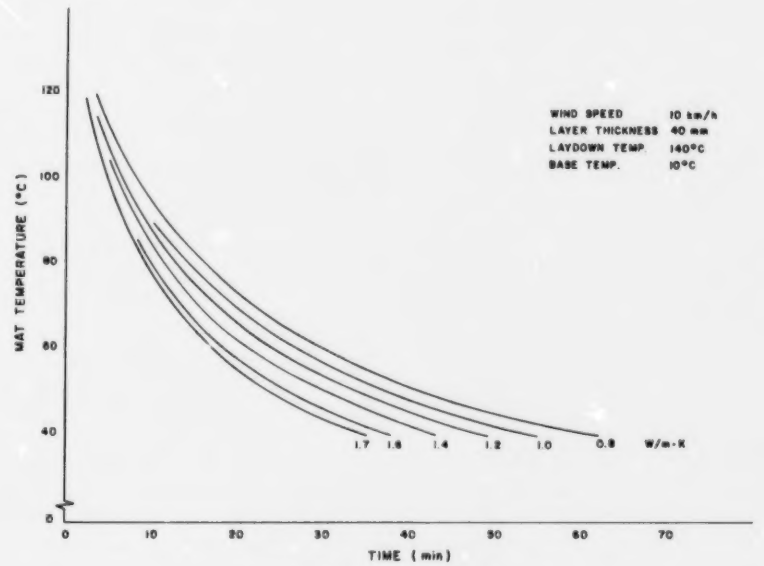

Fig. 13 - EFFECT OF CONDUCTIVITY ON COOLING RATE

This period is not sufficient to compact a pavement adequately in a typical paving operation. Pavements that were not properly compacted during construction will be subject to eventual rutting and ravelling.

Poor compaction and the eventual failure due to rutting and ravelling can also be expected with mixes which contain recycled asphalt pavement. The recycled mixes tend to cool down more rapidly than conventional mix especially if all the moisture has not been removed from the reclaimed asphalt pavement or if the heat transfer process, from the virgin aggregate to the recycled pavement, had not been completed at the time of laydown.

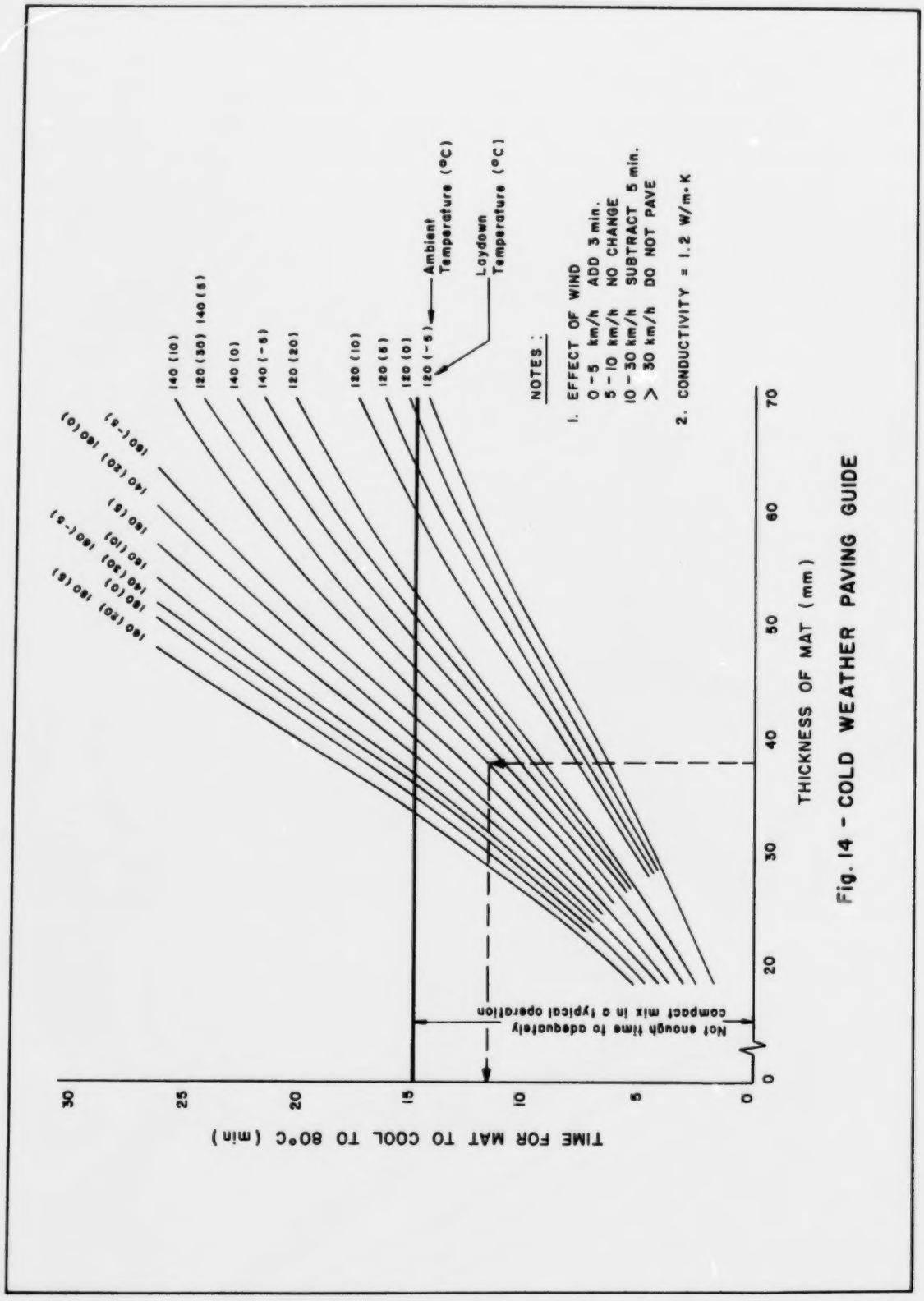

Fig. 14 - COLD WEATHER PAVING GUIDE

3. Air temperature/base temperature relationship

3.1 Purpose

The purpose of this component of the work was to determine if base temperature could replace air temperature as the controlling factor for cold weather paving cessation. Besides the data collected in conjunction with the cooling rate of the mat, a survey of the criteria used by other agencies and a literature search were carried out.

3.2 Field Work

The field work undertaken to determine if base temperature could replace air temperature as the cessation criteria was performed in conjunction with the work described in Chapter 2. Three sets of temperature were recorded: bituminous base temperature prior to paving, shoulder rounding temperature and air temperature. For a complete description of how the readings were recorded see Chapter 2, and for summaries of the data see Appendix A and Figure17.

Work was also done to determine if 5 surface thermometers, purchased for this project, are suitable for field measurements of base temperature. Description of the thermometers is included in Appendix C.

3.3 Observations

In addition to the observations outline in Chapter 2, the following observations were made:

- surface temperatures could not be properly recorded because of difficulties in obtaining an intimate contact with the pavement or granular base being measured.
- the readings of the "barefoot" thermometers (ones with an exposed bi-metal coil) stabilized much faster than the readings of the totally enclosed thermometers.
- the bi-metal coil of the "barefoot" thermometer tended to snag on surface irregularities of the pavement or granular base and tended to trap small pieces of aggregates within the coils.

3.4 Literature search

Very little is available in the literature on the relationship between air temperature near the surface and surface temperature.

Data recorded at Environment Canada meteorological stations, however, indicate that air temperatures and ground temperatures follow the same pattern and are seldom significantly different if the ground is not covered by snow. Figures 15 and 16 show the air and ground temperatures of Atikokan and Elora which were selected as being typical of Northern and Southern Ontario respectively.

3.5 Discussion

The results of our field work, summarized in Figure 17, indicate that, in the Fall, air temperatures (measured 1 m above the surface) and surface temperatures of hot mix pavement or granular materials are essentially the same. This is further supported by the results of Environment Canada data which show that in the Fall air and soil temperatures follow the same pattern and are seldom very different.

3.6 Evaluation of surface thermometers

Five thermometers were evaluated by comparing cost, accuracy, response time, and ruggedness. For each of the above, the thermometers were given a rating ranging from 1 (poor) to 5 (good). These ratings were then multiplied by a relative weight to reflect the importance of the factor, and an overall rating for each thermometer was calculated.

The "cost factor" was the price paid to purchase one thermometer. It does not reflect any possible discount that might be obtained if a large number of thermometers were ordered.

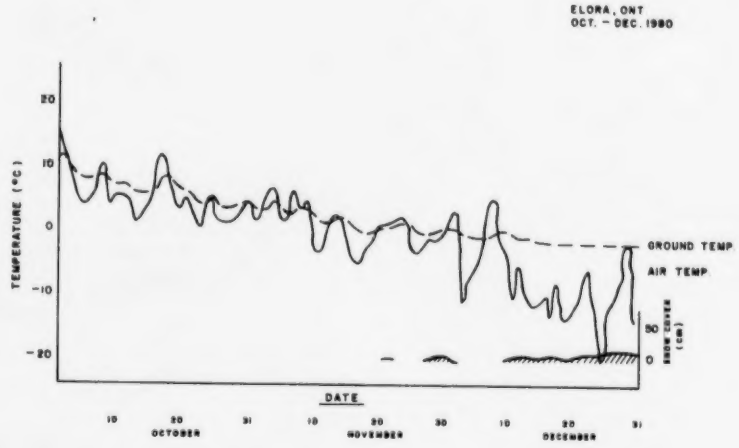

Fig. 15 - FALL AIR/GROUND TEMPERATURE RELATIONSHIP
- ELORA -

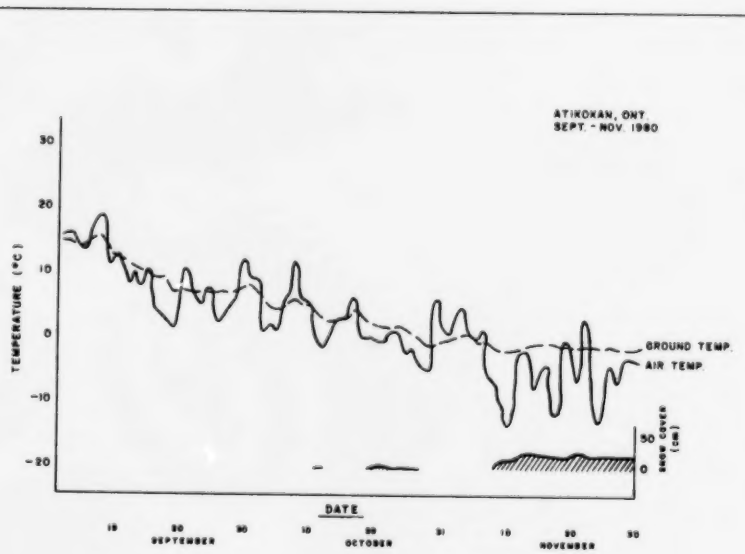

Fig. 16 - FALL AIR/GROUND TEMPERATURE RELATIONSHIP
- ATIKOKAN -

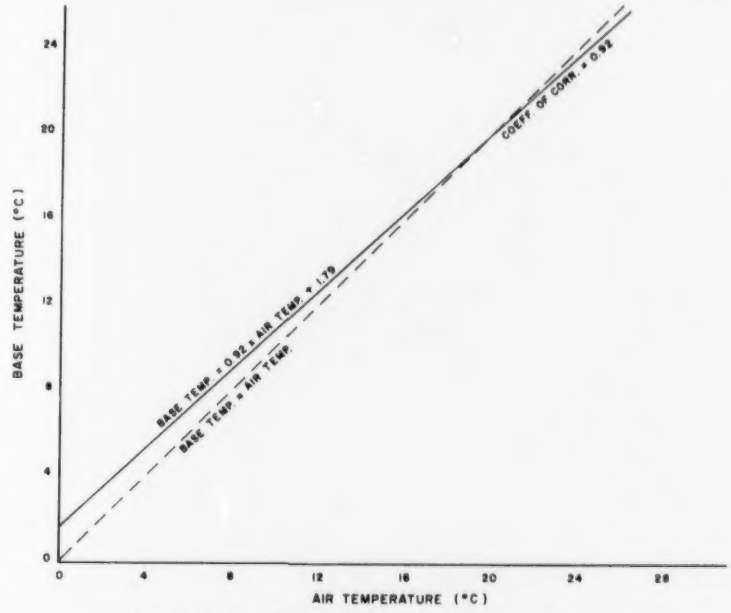

Fig. 17 - BASE TEMPERATURE AIR TEMPERATURE RELATIONSHIP

The "accuracy factor" is a measure of how closely the surface thermometer recorded the temperature of the pavement or of the granular shoulder on which it was placed. The base temperature used for comparison was the temperature measured with a "Pronto" spot probe which had previously been calibrated against laboratory thermometers.

The "response time factor" was based on how long it took the reading of a surface thermometer to stabilize. The results of the accuracy and response time experiments are shown on Tables 1 and 2.

"Ruggedness" was assigned subjective values ranging from good for well enclosed solid thermometers, to poor for fragile thermometers with exposed elements.

Tables 1 and 2 show the results of the performance tests to arrive at the accuracy and response time factors. Table 3 shows the overall evaluation of the thermometers, while appendix B contains a description of the thermometers.

TABLE 1
PERFORMANCE OF SURFACE THERMOMETERS AT 6°C

Thermometer	Temp.of Bituminous Surface (°C)	Response Time (min.)	Temp.of Granular Surface (°C)	Response Time (min.)
P.T.Model 309C	6	5	5	5
P.T.Model 310C	7	5	6	5
P.T.Model 312C	6	3.5	5*	3.5
P.T.Model 674C	5	2.5	5*	2.5
Alexander Wig CN Model	6.5	20	5	15
Control	6.0	-	4	-

* reading affected by surface roughness and aggregates.

TABLE 2
PERFORMANCE OF SURFACE THERMOMETERS AT -1°C

Thermometer	Temp.of Bituminous Surface (°C)	Response Time (min.)	Temp.of Granular Surface (°C)	Response Time (min.)
P.T.Model 309C	-1	5	-2	5
P.T.Model 310C	0	5	-1	5
P.T.Model 312C	-2	3	-1	2.5
P.T.Model 674C	-2 off scale reading estimated	2.5	-2 off scale reading estimated	2
Alexander Wig CN Model	0	20	-1	20
Control	-1	-	-2	-

TABLE 3
EVALUATION OF THERMOMETERS

Thermometer / Relative Weight of Factor	Cost	Accuracy	Response Time	Ruggedness	Overall Rating
	2	2	1	3	
P.T. Model 309C	1	5	4	4	28
P.T. Model 310C	4	1	4	4	26
P.T. Model 312C	4	3	4	1	21
P.T. Model 674C	5	1	5	1	20
Alexander Wig CN Model	3	2	1	5	26

Based on the above the Pacific Transducer Corporation model number 309C rated best overall followed closely by the Pacific Transducer Corporation model 310C and the Alexander Wig CN track thermometer. If purchased in large quantities it is likely that the #309C without attachments would probably be in the $20-30 range making it the most likely choice.

The other thermometers were not considered acceptable for field use.

4. Conclusions and Recommendations

1. Hot mix laid in the fall under the present specifications might not be compacted to its optimum density. Work carried out for this study and the literature review suggest that the mat cools down too rapidly to be adequately compacted. This is especially true of thin lifts (<50 mm) and of mix containing large proportion of recycled asphalt pavement.

Recommendation 1

Retain the present specifications governing paving cessation due to low temperature.

2. The literature suggests that base temperature has a much greater effect on the cooling rate of a mat than does air temperature. It was found, however, that in the Fall the air temperatures near the surface and the base temperatures are essentially the same. Also, it was found that base temperatures are difficult to measure accurately.

Recommendation 2

Retain air temperature, measured near the surface, as the paving cessation criteria.

5. Acknowledgements

The authors would like to acknowledge the co-operation of the contractors on whose projects data was collected:

- Smiths Construction, Cont. 80-51, Hwy. 60
- King Paving, Cont. 81-20, Hwy. 5
- Repac Construction, Cont. 80-55, Hwy. 401
- Raney Limited, Cont. 81-48, Hwy. 406
- M.B.L. International, Cont. 80-04, E. C. Row

Thanks also to Irene Sotnyk, of the Electrical Design Section, for preparing the figures and to Nina DeRocchis for typing this report.

6. References

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7. Appendix

Appendix A

Field notes

DATE: 81-10-13 Contract 80-51 Highway 60 Lane E/B Station 14 + 25 No. 1

TIME (MIN)	TEMP. OF BASE OF MAT (°C)	TEMP. AT MIDDLE OF MAT (°C)	TEMP. AT TOP OF MAT (°C)	WIND SPEED (Km/h)	AIR TEMP. (°C)	SHOULDER TEMP.(°C)	REMARKS	THEORETICAL TEMP.	
								Time min.	Temp. °C
1:50	19	-	-	-	17	-	Weather-Sunny		
2:20	20	-	-	-	-	-			
2:36	15	-	-	-	18	-	Type of Material-Recycled HL4 (50mm)		
2:37- 0	-	-	-	-	-	-	Mix Temperature - 133°C		
1	28	119	-	0	-	-	70:30 mix	0	133
3	42	113	126	0-2	18	-		3	120
5	47	101	122	0	-	-	First pass of roller at 5 min.	7	110
7	49	98	122	0	18	-		11	100
9	49	96	119	0	18	-		16	90
11	51	92	112	0	18	-		23	80
13	50	87	104	0	18	-		32	70
15	52	85	100	0	18	-		46	60
18	53	81	94	0	18	-		68	50
23	57	77	88	0	19	-		111	40
28	55	74	84	0	-	-			
33	55	71	80	0	19	-	Last pass of r/t roller at 33 min.		
38	55	70	76	0	-	-	Wind Speed	km/h	0
43	55	66	73	0	19	-	Conductivity	W/m.K	1.7
48	51	65	65	0	-	-	Layer Thickness	mm	50
53	51	60	63	0	19	-	Laydown Temperature	°C	133
							Base Temperature	°C	18

DATE: 81-10-14 Contract 80-51 Highway 60 Lane E/B Station 162 + 50 No. 2

TIME (MIN)	TEMP. OF BASE OF MAT (^{o}C)	TEMP. AT MIDDLE OF MAT (^{o}C)	TEMP. AT TOP OF MAT (^{o}C)	WIND SPEED (Km/H)	AIR TEMP. (^{o}C)	SHOULDER TEMP.(^{o}C)	REMARKS	THEORETICAL TEMP.	
								Time min.	Temp. ^{o}C
9:15	-1	-	-	0	1	-	Weather - Sunny		
9:45- 1	1	5	95	0	5	0			
4	27	88	102	0	-	-	Type of Material-Recycled HL4 (50mm)		
7	40	91	100	0	6	2	Mix Temperature - 143^{o}C		
10	44	-	115	0	6	-	-70:30 mix		
13	48	-	107	0	7	-			
16	48	-	102	0	7	-	-First pass of roller at 10 min.		
23	50	*	87	0	8	-			
29	51		80	0	9	3	-* wire damaged by truck		
35	50		70	0	9	-			
40	49		62	0	9	-	-Last pass of r/t roller at 19 min.		
45	48		50	0	-	-			
52	46		55	0	10	-			
57	46		52	0	-	-			
60	45		50	0	11	-			
62	45		49	0	-	-			
75	41		43	0	-	4			

DATE: 81-10-14 Contract 80-51 Highway 60 Lane E/B Station 162 + 50 No. 3

TIME (MIN)	TEMP. OF BASE OF MAT (^{o}C)	TEMP. AT MIDDLE OF MAT (^{o}C)	TEMP. AT TOP OF MAT (^{o}C)	WIND SPEED (Km/h)	AIR TEMP. (^{o}C)	SHOULDER TEMP.(^{o}C)	REMARKS	THEORETICAL TEMP. Time min.	THEORETICAL TEMP. Temp. ^{o}C
2:10	16	-	-	0-5	18	-	Weather - Sunny		
2:30	21	-	-	-	-	-			
2:37- 0	44	-	-	0-3	18	9	Type of Material-Recycled HL4 (50mm)		
3	47	65	88	0-3	-	-	Mix Temperature - 135^{o}C		
5	48	63	78	0-3	-	-	-70:30 mix		
7	47	63	80	0-3	-	-			
9	46	59	93	0	18	-	-First pass of b/d roller at 9 min.		
11	46	57	91	0	-	-			
13	45	58	86	0	-	15			
15	47	57	81	0	19	-			
17	49	55	78	0	19	-			
21	46	55	70	0	-	-			
24	46	54	66	0	-	15			
32	46	51	59	0-5	19	-			
43	44	47	56	0	18	14			
48	44	46	50	0	-	-	-Last pass of r/t roller at 48 min.		
53	43	46	50	0	-	-	-Note: Paver stopped on thermocouple		
58	42	44	49	0	18	-	for 5 minutes - grade not		
63	42	44	47	0-5	18	-	prepared ahead.		

DATE: 81-10-20 Contract 80-51 Highway 60 Lane W/B Station 358 + 00 No. 4

TIME (MIN)	TEMP. OF BASE OF MAT (°C)	TEMP. AT MIDDLE OF MAT (°C)	TEMP. AT TOP OF MAT (°C)	WIND SPEED (Km/h)	AIR TEMP. (°C)	SHOULDER TEMP.(°C)	REMARKS	THEORETICAL TEMP. Time min.	Temp. °C
3:30	9	-	-	5-10	12	9	Weather - Cloudy occasional showers		
3:40	9	-	-	0-5	11	9	Type of Material-Recycled HL4 (50 mm)		
3:44- 0	56	-	-	3	11	9	Mix Temperature - 135°C	0	135
6	61	93	105	3	11	9	-70:30 Mix	3	120
11	61	89	102	3	11	10	-First pass of b/d roller at 6 min.	5	110
13	60	86	98	4	10	10		8	100
15	59	82	92	3-5	10	10		11	90
18	59	79	86	5	-	10		16	80
21	60	75	82	5	11	10	-Last pass of r/t roller at 21 min.	22	70
24	58	71	78	3-5	11	10		30	60
26	57	68	75	3-5	11	10		43	50
29	55	63	71	5	11	10		63	40
32	54	62	68	3-5	11	10			
35	53	60	66	5	11	10			
39	51	57	61	6-10	11	-			
45	47	50	54	0-5	11	9			
56	44	47	50	5	11	9	Wind Speed	km/h	4
61	43	45	47	5	11	9	Conductivity	W/m.K	1.7
66	41	43	44	5	11	-	Layer Thickness	mm	50
71	39	41	39	5	11	9	Laydown Temperature	°C	135
76	38	38	34	5	11	-	Steady rain Base Temperature	°C	9

DATE: 81-10-21 Contract 80-51 Highway 60 Lane E/B Station 376 + 00 No. 5

TIME (MIN)	TEMP. OF BASE OF MAT (°C)	TEMP. AT MIDDLE OF MAT (°C)	TEMP. AT TOP OF MAT (°C)	WIND SPEED (Km/h)	AIR TEMP. (°C)	SHOULDER TEMP.(°C)	REMARKS	THEORETICAL TEMP.	
10:25	3	-	-	0	4	3	Weather - Partly Cloudy		
10:40- 0	-	-	-	0	5	3			
1	45	118	95	0	5	3	Type of Material-Recycled HL4 (50mm)	Time min.	Temp. °C
3	41	114	94	0	4	3	Mix Temperature - 131°C		
5	43	110	91	0	5	4	-70:30 mix	0	131
9	48	100	85	0	5	5		2	120
12	49	94	78	0	5	5		5	110
14	48	88	80	2	4	5		9	100
16	50	89	69	0	4	5	-First pass of b/d roller at 14 min.	13	90
18	50	83	57	0	3	-		18	80
19	51	82	68	0	4	5	-Last pass of r/t roller at 25 min.	24	70
22	51	77	60	0	4	5		33	60
24	50	74	57	0	4	5		46	50
27	50	69	57	0	4	5	-whenever roller passed over top of	67	40
29	49	65	51	0	3	5	mat, probe temperature jumped up-		
35	48	61	43	0	3	-	probable cause		
40	47	57	43	0	3	4	poor contact with mat		
45	45	52	39	0	3	4	Wind Speed	km/h	0
52	43	49	37	2	3	4	Conductivity	W/m.K	1.7
60	40	45	34	0	4	4	Layer Thickness	mm	50
72	37	40	39	0	4	4	Laydown Temperature	°C	131
							Base Temperature	°C	4

DATE: 81-10-29 Contract 80-55 Highway 401 Lane E/B Station 381 + 50 D/L No. 6

TIME (MIN)	TEMP. OF BASE OF MAT (°C)	TEMP. AT MIDDLE OF MAT (°C)	TEMP. AT TOP OF MAT (°C)	WIND SPEED (Km/h)	AIR TEMP. (°C)	SHOULDER TEMP.(°C)	REMARKS	THEORETICAL TEMP.	
								Time min.	Temp. °C
11:00	12	-	-	3	9		Weather - Sunny with cloudy		
11:05	12	-	-	-	8		intervals		
11:13- 0	88	85	-	-	-		Type of Material-DCF on HL8 Base		
2	77	86	108	-	-		Mix Temperature - 151°C		
4	76	83	105	0	8		-* contact with thermocouple lost		
5	76	81	104	-	8				
7	76	79	98	-					
9	71	74	94	2	-				
11	70	90	90	2	7		-First pass of b/d roller at 3 min.		
14	70	*	82	-	-				
16	69		78	2	7		-Last pass of r/t roller at 62 min.		
19	67		72	2	8	14			
21	65		69	2	-				
25	60		63	-	-				
30	57		56	-	-				
35	55		52	-	-				
40	55		47	2	6				
45	52		45	2	-				
50	50		41	1	9				
60	45		36	2	8				
62	44		36	0	7				

DATE: 81-10-30 Contract 80-55 Highway 401 Lane Shoulder Station 249 + 35 No. 7

TIME (MIN)	TEMP. OF BASE OF MAT (°C)	TEMP. AT MIDDLE OF MAT (°C)	TEMP. AT TOP OF MAT (°C)	WIND SPEED (Km/h)	AIR TEMP. (°C)	SHOULDER TEMP.(°C)	REMARKS	THEORETICAL TEMP. Time min.	Temp. °C
12:40	14	15	-	3	13	13	Weather - Sunny		
12:45- 0	90	105	133	0	13	13			
2	86	116	133	2	-	13	Type of Material-HL4 (38mm)		
4	85	113	129	2	13	13	Mix Temperature - 161°C		
7	88	108	121	-	-	13	-First pass of b/d roller at 2 min.	0	161
9	86	103	118	-	12	13		3	140
10	86	102	113	2	12	13		4	130
12	84	96	105	-	13	13		6	120
14	83	90	98	3	13	13		9	110
16	80	87	94	3	13	13		12	100
19	77	82	88	4	13	13		16	90
21	74	79	83	5	13	13		20	80
24	72	75	79	4	14	13	-Last pass of r/t roller at 19 min.	27	70
26	71	73	76	-	-	13		36	60
30	66	68	70	-	-	13		51	50
36	62	62	63	5	14	13		76	40
40	60	60	60	3	14	13	Wind Speed	km/h	3
45	57	57	56	-	-	13	Conductivity	W/m.K	1.4
50	53	53	53	4	13	13	Layer Thickness	mm	38
60	51	50	49	4	13	13	Laydown Temperature	°C	161
75	46	45	45	4	13	13	Base Temperature	°C	13

DATE: 81-10-30 Contract 80-55 Highway 401 Lane Shoulder Station 333 + 75 No. 8

TIME (MIN)	TEMP. OF BASE OF MAT (°C)	TEMP. AT MIDDLE OF MAT (°C)	TEMP. AT TOP OF MAT (°C)	WIND SPEED (Km/h)	AIR TEMP. (°C)	SHOULDER TEMP.(°C)	REMARKS	THEORETICAL TEMP. Time min.	Temp. °C
11:10	17	17	-	4	16	14	Weather - Sunny		
11:14- 0	59	135	-	3	-	14			
1	74	135	130	4	-	14	Type of Material - HL4		
2	77	134	133	4	-	14	Mix Temperature - 163°C		
4	77	128	131	4	16	14	-First pass of b/d roller at 12 min.	0	163
6	79	123	127	4	17	14	-Last pass of r/t roller at 28 min.	3	140
8	78	120	123	-	-	14		5	130
10	80	116	119	4	-	14		7	120
12	80	111	114	4	-	-		9	110
14	79	108	108	-	17	-		11	100
16	78	105	104	-	-	-		16	90
18	81	103	99	4	-	-		20	80
20	77	99	102	-	-	-		27	70
22	78	95	98	-	-	-		36	60
26	77	90	92	4	18	-		51	50
30	74	86	87	-		-			
35	72	84	84	6	-	-			
40	71	78	77	-	-	-	Wind Speed	km/h	4
45	70	74	73	8	-	-	Conductivity	W/m.K	1.4
50	67	71	70	7	-	-	Layer Thickness	mm	38
60	63	66	64	10	18	-	Laydown Temperature	°C	163
75	58	59	58	10	18	-	Base Temperature	°C	14

DATE: 81-11-02 Contract 80-55 Highway 401 Lane Shoulder Station 356 + 50 No. 9

TIME (MIN)	TEMP. OF BASE OF MAT (°C)	TEMP. AT MIDDLE OF MAT (°C)	TEMP. AT TOP OF MAT (°C)	WIND SPEED (Km/h)	AIR TEMP. (°C)	SHOULDER TEMP.(°C)	REMARKS	THEORETICAL TEMP. Time min.	Temp. °C
1:20	18	19	-	0	18	16	Weather - Sunny with		
1:28- 0	111	114	122	0	18	16	cloudy periods		
1	112	114	129	4	-	16	Type of Material - HL4		
2	107	115	128	-	-	16	Mix Temperature - 172°C		
4	104	109	121	4	18	16	-First pass of b/d roller at 2 min.		
6	104	105	114	4	18	16			
8	101	100	104	-	-	16	-Last pass of r/t roller at 45 min.		
10	98	96	97	4	18	16			
12	86	97	90	4	-	16			
14	85	92	89	-	18	16			
16	81	88	86	5	-	16			
18	80	84	84	-	-	16			
20	76	78	79	5	-	16			
22	75	78	77	-	-	16			
26	71	73	74	5	18	16			
30	67	68	67	-	-	16			
35	63	63	61	7	17	16			
40	59	59	57	-	-	16			
45	56	56	54	10	-	16			
50	54	53	51	10	17	16			
60	47	46	44	-	-	16			
75	41	41	40	8	16	16			

DATE: 81-11-03 Contract 80-55 Highway 401 Lane Shoulder Station 417 + 50 No. 10

TIME (MIN)	TEMP. OF BASE OF MAT (°C)	TEMP. AT MIDDLE OF MAT (°C)	TEMP. AT TOP OF MAT (°C)	WIND SPEED (Km/h)	AIR TEMP. (°C)	SHOULDER TEMP.(°C)	REMARKS	THEORETICAL TEMP.	
								Time min.	Temp. °C
11:45	18	15	-	4	10	-	Weather - Sunny		
11:55- 0	33	126	-	3	12	-			
2	35	116	118	3	12	-	Type of Material - HL4 (50mm)		
4	60	105	126	3	-	-	Mix Temperature - 161°C		
6	65	90	125	-	-	-	-First pass of b/d roller at 3 min.		
8	64	87	122	-	-	-			
10	66	84	117	2	12	-	- water on surface		
13	68	82	109	-	-	-			
14	68	81	107	-	-	-	-Last pass of r/t roller at 60 min.		
16	67	80	103	2	12	-			
18	68	78	99	-	-	-			
20	67	76	97	-	-	-			
22	68	76	93	2	13	-			
25	64	73	88	-	-	-			
30	64	70	83	0	13	-			
35	64	68	77	-	-	-			
40	61	65	63*	-	-	-			
45	60	63	54	-	-	-			
50	58	61	52	2	12	-			
60	53	56	51	-	-	-			
75	49	51	49	2	12	-			

DATE: 81-11-04 Contract 80-55 Highway 401 Lane E/B D/L Station 420 + 00 No. 11

TIME (MIN)	TEMP. OF BASE OF MAT (°C)	TEMP. AT MIDDLE OF MAT (°C)	TEMP. AT TOP OF MAT (°C)	WIND SPEED (Km/h)	AIR TEMP. (°C)	SHOULDER TEMP.(°C)	REMARKS	THEORETICAL TEMP. Time min.	THEORETICAL TEMP. Temp. °C
1:30	21	19	-	2	16	-	Weather - Cloudy		
1:37- 0	37	61	-	-	-	-			
1	45	66	118	-	-	-	Type of Material - DFC (mm)		
2	62	66	117	-	-	-	Mix Temperature - 153°C		
4	65	68	112	3	15	-	-First pass of b/d roller at 1 min.		
6	66	68	110	-	-	-			
8	65	67	104	-	-	-	-*wire to probe cut		
10	57	70	92	-	-	-	by roller		
12	57	67	88	2	16	-			
14	56	64	83	-	-	-	-Last pass of r/t roller at		
16	56	62	79	3	16	-	35 min.		
18	55	60	75	-	-	-			
20	53	57	-*	-	-	-			
24	51	52		-	-	-			
30	48	51		-	-	-			
35	47	48		5	15	-			
40	42	43		6	15	-			
45	42	42		6	15	-			
50	39	39		4	14	-			
60	37	37		-	-	-			

DATE: 81-11-05 Contract 80-55 Highway 401 Lane Ramp Station Courtice Rd. Ramp No. 12

TIME (MIN)	TEMP. OF BASE OF MAT (°C)	TEMP. AT MIDDLE OF MAT (°C)	TEMP. AT TOP OF MAT (°C)	WIND SPEED (Km/h)	AIR TEMP. (°C)	SHOULDER TEMP.(°C)	REMARKS	THEORETICAL TEMP.	
								Time min.	Temp. °C
12:35	22	16	-	2	14	-	Weather - Sunny		
12:40	21	15	-	2	14	-			
12.41- 0	54	92	-	-	-	-	Type of Material - DFC (mm)		
2	59	94	115	3	15	-	Mix Temperature - 146°C		
4	58	94	109	2	15	-			
6	54	94	98	-	15	-	-drag on wires during parting		
8	52	94	90	-	-	-			
12	48	85	81	-	-	-	-*no signal from thermocouple		
15	49	82	73	3	12	-			
17	-*	78	68	-	-	-			
20	-	76	65	3	12	-	-First pass of b/d roller at 6 min.		
22	-	73	62	3	12	-			
27	-	66	55	-	-	-	-Last pass of r/t roller at 67 min.		
30	-	63	53	2	12	-			
35	-	58	48	2	11	-			
40	-	54	44	5	11	-			
45	-	50	41	3	11	-			
50	34	48	37	-	-	-			
55	30	45	35	2	-	-			
60	28	43	34	-	11	-			
75	-	38	30	2	10	-			

DATE: 81-11-09 Contract 81-20 Highway 5 Lane D/L E/B Station 294 + 00 No. 13

TIME (MIN)	TEMP. OF BASE OF MAT (°C)	TEMP. AT MIDDLE OF MAT (°C)	TEMP. AT TOP OF MAT (°C)	WIND SPEED (Km/h)	AIR TEMP. (°C)	SHOULDER TEMP.(°C)	REMARKS
1:50	9	6	-	7	3	-	Weather - Sunny
2:00- 0	137	96	-	-	-	-	
2	104	111	131	7	4	-	Type of Material - HL8 (38mm)
4	97	110	121	-	4	-	Mix Temperature - 164°C
6	97	117	113	-	-	-	
8	90	112	108	5	4	-	-First pass of b/d roller at 6 min.
10	88	106	97	-	-	-	
12	87	101	92	3	4	-	-Last pass of r/t roller at 10 min.
14	84	95	85	-	-	-	
16	82	91	79	3-5	4	-	
18	80	87	76	-	-	-	
20	78	84	72	-	-	-	
22	76	80	68	-	-	-	
25	73	76	63	5-7	4	-	
30	67	69	57	6	4	-	
35	63	64	54	7	4	3	
40	59	59	50	-	-	-	
45	55	55	46	3	4	-	
50	52	51	43	-	-	-	
60	47	46	39	3	3	3	
75	41	40	32	3-5	3	-	

THEORETICAL TEMP.			
		Time min.	Temp. °C
		0	164
		5	120
		7	110
		9	100
		11	90
		14	80
		18	70
		24	60
		32	50
		45	40
Wind Speed	km/h	5	
Conductivity	W/m.K	1.7	
Layer Thickness	mm	38	
Laydown Temperature	°C	164	
Base Temperature	°C	4	

DATE: 81-11-10 Contract 81-20 Highway 5 Lane D/L E/B Station 294 + 00 No. 14

TIME (MIN)	TEMP. OF BASE OF MAT (°C)	TEMP. AT MIDDLE OF MAT (°C)	TEMP. AT TOP OF MAT (°C)	WIND SPEED (Km/h)	AIR TEMP. (°C)	SHOULDER TEMP.(°C)	REMARKS	THEORETICAL TEMP. Time min.	Temp. °C
1:15	9	7	-	6	3	-	Weather - Sunny with		
1:20- 0	90	117	108	-	-	-	cloudy periods		
2	85	110	114	7	4	-	Type of Material - HL8 (38mm)		
4	80	98	127	-	-	-	Mix Temperature - 164°C		
6	75	93	121	7	3	-			
8	75	89	113	7	3	-	-First pass of b/d roller at 3 min.		
10	74	86	111	6	3	-			
12	73	83	100	-	-	-	-Last pass of r/t roller at 22 min.		
14	71	80	95	7	3	-			
16	69	77	91	-	-	-			
18	68	75	87	7	3	-			
20	67	72	80	-	-	-			
22	60	70	78	7	4	-			
27	63	65	69	-	-	-			
30	60	63	66	7	3	-			
35	55	58	60	7	3	-			
40	53	54	55	7	3	-			
45	51	49	51	-	-	-			
50	49	48	50	7	4	-			
60	43	44	43	6	3	-			
75	39	39	38	5	4	-			

DATE: 81-11-30 Contract 80-04 Highway E.C. Row Lane D/L E/B Station 210 + 20 No. 15

TIME (MIN)	TEMP. OF BASE OF MAT (°C)	TEMP. AT MIDDLE OF MAT (°C)	TEMP. AT TOP OF MAT (°C)	WIND SPEED (Km/h)	AIR TEMP. (°C)	SHOULDER TEMP.(°C)	REMARKS	THEORETICAL TEMP. Time min.	Temp. °C
4:20	5	-	-	-	2	2	Weather - Partly cloudy		
4:25- 0	33	72	-	0	2	-			
2	52	94	110	-	2	-	Type of Material-Steel Slag DFC(38mm)		
4	59	101	122	-	2	-	Mix Temperature - 147°C		
6	59	98	122	3	-	-		0	147
8	60	96	120	-	1	-	-First pass of b/d roller at 8 min.	3	130
11	58	90	110	-	-	-		5	120
13	57	86	104	-	-	-	-Last pass of r/t roller at 35 min.	8	110
15	57	82	99	2	-	-		11	100
17	57	78	93	-	1	-	-Concrete base	15	98
20	54	74	87	-	-	-		20	80
25	51	67	77	0	-	-		27	70
30	47	61	66	0	-	-		35	60
35	45	56	58	3	1	2		47	50
40	43	52	52	-	-	-		66	40
45	41	46	46	5	2	-	Wind Speed	km/h	1
55	36	40	38	-	-	-	Conductivity	W/m.K	0.8
60	35	38	34	3	1	-	Layer Thickness	mm	38
65	33	35	32	3	1	-	Laydown Temperature	°C	147
							Base Temperature	°C	2

DATE: 81-12-01 Contract 80-04 Highway E.C. Row Lane Shoulder Station 212 + 90 No. 16

TIME (MIN)	TEMP. OF BASE OF MAT (°C)	TEMP. AT MIDDLE OF MAT (°C)	TEMP. AT TOP OF MAT (°C)	WIND SPEED (Km/h)	AIR TEMP. (°C)	SHOULDER TEMP.(°C)	REMARKS	THEORETICAL TEMP.	
								Time min.	Temp. °C
2:30	8	-	-	7	8	8	Weather - Cloudy with		
3:05	8	-	-	6	9	-	sunny periods		
3:10- 0	37	90	-	-	-	-	Type of Material - HL4 (38mm)		
1	46	89	111	2	9	-	Mix Temperature - 134°C		
2	50	87	112	6	9	-			
4	54	83	110	5	9	-	-First pass of b/d roller at 4 min.		
6	57	80	106	-	-	-			
8	57	78	101	7	9	8	-Last pass of r/t roller at 45 min.		
10	58	75	94	-	-	-			
12	59	74	84	-	-	-			
14	59	71	78	-	-	-			
16	58	69	75	4	-	-			
18	56	66	71	-	-	-			
23	53	62	64	-	-	-			
29	50	56	58	-	-	-			
35	48	51	47	3	8	-			
42	43	45	42	4	8	-			
45	43	43	42	6	-	-			
50	39	41	39	4	8	-			
60	35	36	33	-	8	-			
70	33	33	31	4	-	-			
75	31	31	29	4	8				

DATE: 81-12-02 Contract 80-04 Highway E.D. Row Lane RAMP Station Huron Church Ramp No. 17

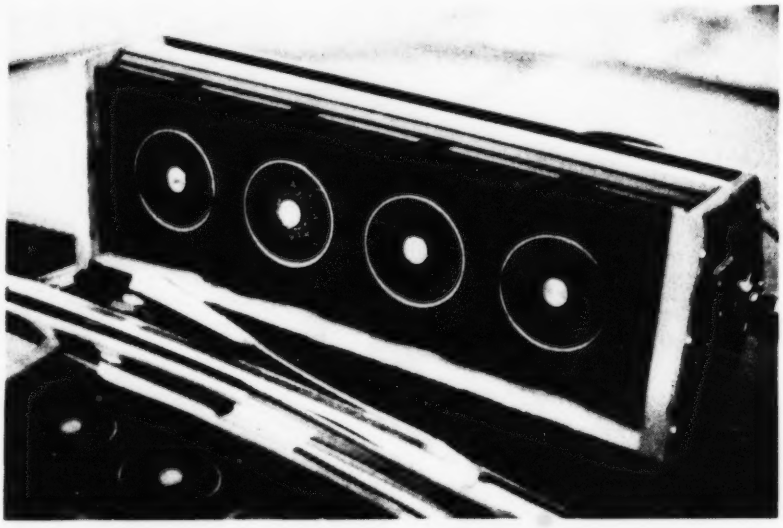
TIME (MIN)	TEMP. OF BASE OF MAT (°C)	TEMP. AT MIDDLE OF MAT (°C)	TEMP. AT TOP OF MAT (°C)	WIND SPEED (Km/h)	AIR TEMP. (°C)	SHOULDER TEMP.(°C)	REMARKS	THEORETICAL TEMP.	
								Time min.	Temp. °C
10:15	4	-	-	10	3	-	Weather - Cloudy with		
10:20- 0	75	88	-	-	-	-	snow flurries		
1	64	98	123	5	4	-	Type of Material-Steel Slag DFC(38mm)		
2	64	104	118	5	3	-	Mix Temperature - 150°C		
4	70	109	115	-	-	-		0	150
6	66	107	112	5	-	-	-First pass of b/d roller at 4 min.	3	130
8	61	99	106	7	3	-		5	120
10	58	92	101	-	-	-	-Last pass of r/t roller at 60 min.	7	110
12	57	88	97	8	3	-		9	100
14	56	84	91	-	-	-		13	90
17	60	79	83	10	3	-		17	80
20	57	72	76	12	3	-		22	70
25	53	64	67	-	-	-		29	60
33	48	55	56	7	3	-		39	50
37	46	52	51	10	2	-		54	40
42	44	48	47	10	2	-	Wind Speed	km/h	8
47	41	44	43	7	-	-	Conductivity	W/m.K	0.8
50	40	42	41	7	2	-	Layer Thickness	mm	380
60	37	37	35	7	3	-	Laydown Temperature	°C	150
75	32	33	29	7	3		Base Temperature	°C	3

Appendix B - Equipment

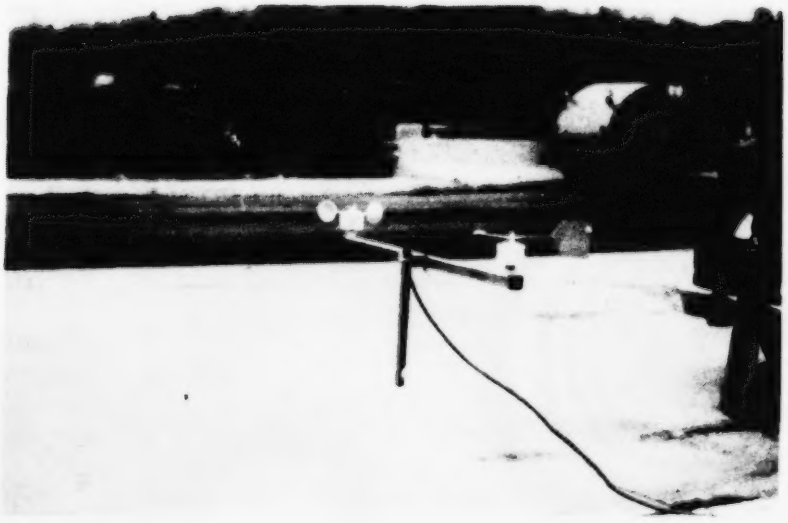
The following equipment was used during the various experiments.

B.1 Anemometer

An anemometer, powered by a car battery via a power inverter, was used to monitor wind speed. The sending unit of the anemometer was located approximately 1 m above the shoulder. The sending unit stand was also used to support the thermocouple used to measure air temperature.



Anemometer Display Panel



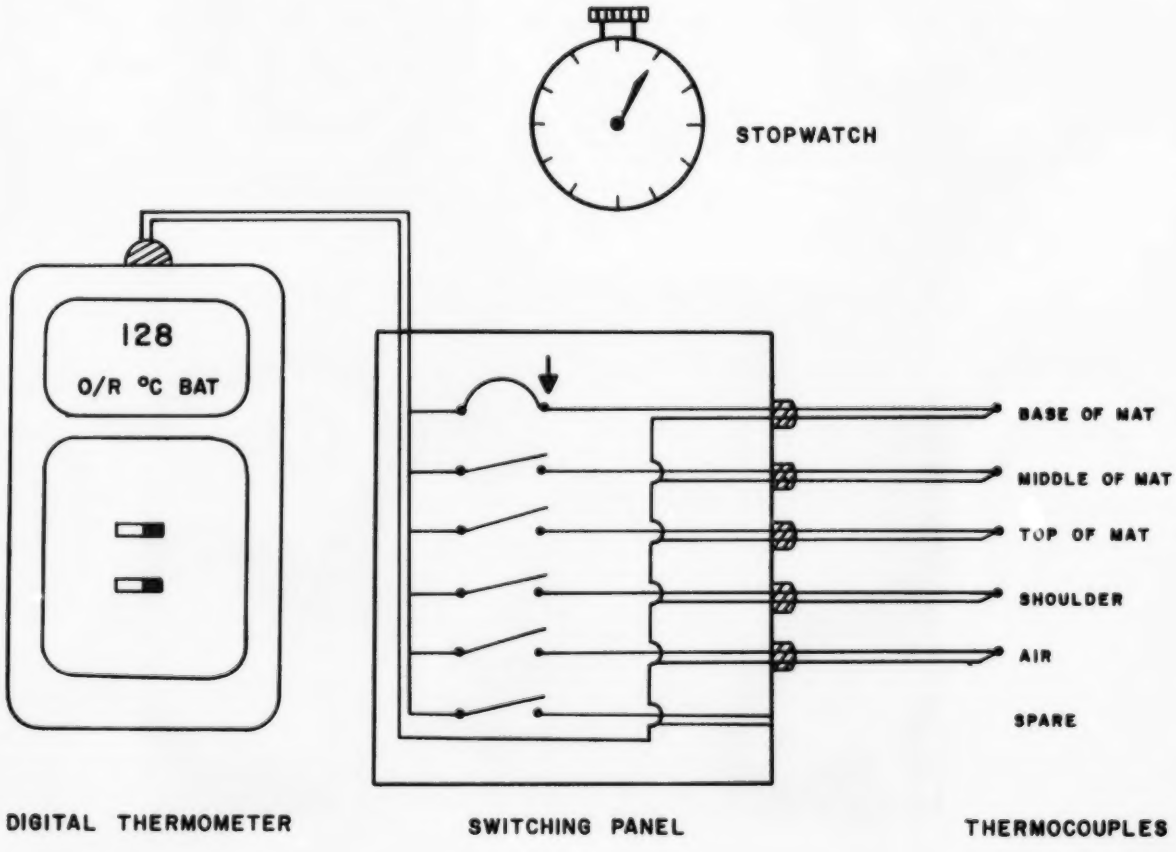
Anemometer Sending unit and thermocouple

B.2 Thermometers

B.2.1 Digital thermometer

Base, mat and air temperatures were monitored by using a digital thermometer to which were attached various probes supplied by the manufacturers. For the majority of the work, however, the digital thermometer was used in conjunction with thermocouples. The various thermocouple wires were brought into a switching panel and from there to the meter.

This arrangement, shown on the following sketch allowed the technician to take 4 or 5 readings in rapid succession.



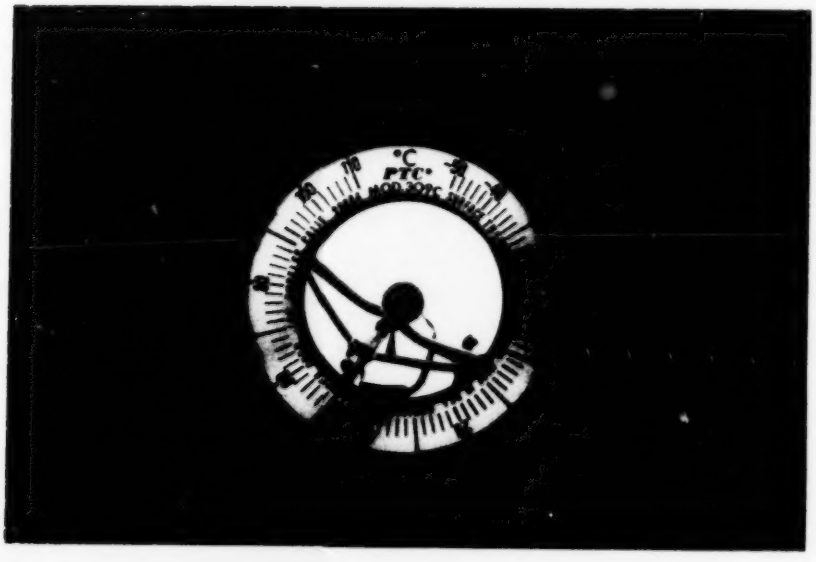
B.2.2 Surface thermometers

All the thermometers tested were of the bi-metal variety. Changes in temperature cause a contraction or an expansion of the bi-metal strip. This change in length causes a needle to move and to show the temperature on a dial.

B.2.2.1 Thermometer 1, Pacific Transducer Corporation Model 309C

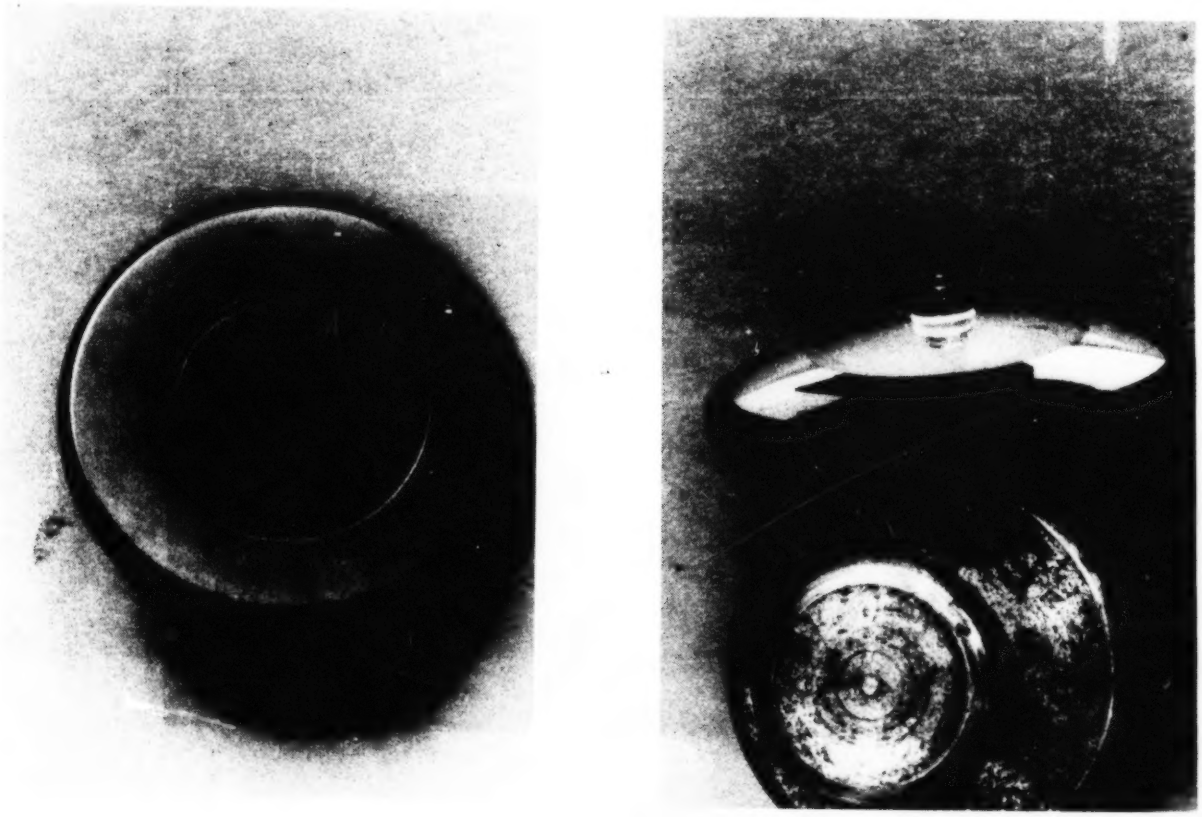
The sensing element and dial of this thermometer are enclosed within a 50 mm diameter body. Heat from the surface being measured is transmitted to the body of the instrument and from it to the air within. The air, in turn, heats up the bi-metal strip which is suspended from the glass cover.

The range of the instrument is - 50°C to 110°C and graduations are marked every 2C°. The cost of the thermometer plus a magnet to hold it in place on ferrous metals and 14 gm of silicone gel, to assure adequate contact, is $44.61.



Thermometer Model PTC 309C

top view



Bottom and Side View of PTC model 309C (PTC model 310C - identical except for scale).

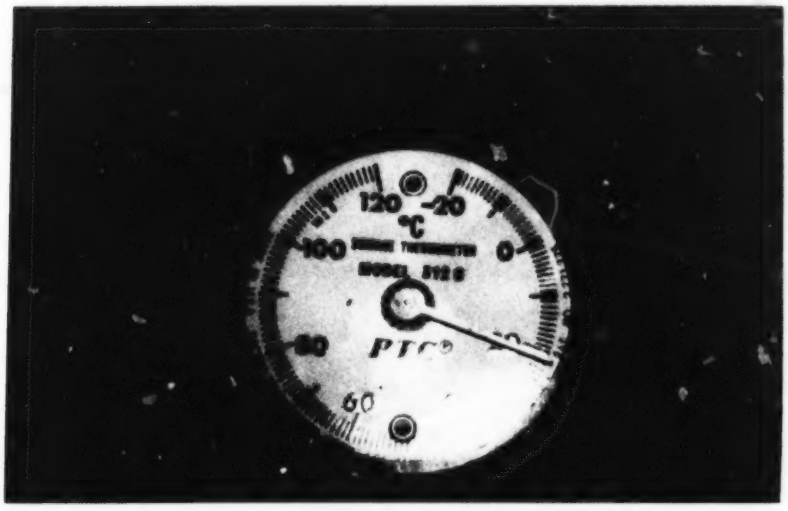
B.2.2.2 Thermometer 2, Pacific Transducer Corporation Model 310C

This thermometer has the same type of construction as thermometer 1 except that the scale ranges from - 10°C to 150°C. The cost is $22.65.

Pacific Transducer Corporation Model 310C
top view

B.2.2.3 Thermometer 3, Pacific Transducer Corporation Model 312C

This 50 mm diameter thermometer differs from the previous two in that it is a "barefoot" thermometer. The bi-metallic spring is exposed and can come in direct contact with the body whose temperature is being measured. The range of the thermometer is from - 20°C to 12°C with 1C° graduations. The cost of the thermometer is $22.35.



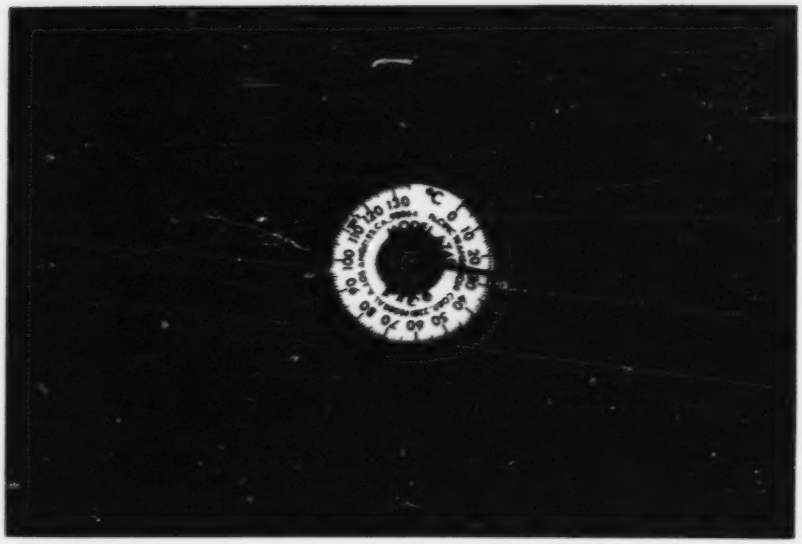
PTC Model 312C
top view

PTC Model 312C
bottom view

Note: piece of aggregate caught in spring during experiment.

B.2.2.4 Thermometer 4, Pacific Transducer Corporation Model No. 674C

The sensing element and the dial of this very small thermometer (20 mm diameter) are exposed. The range of the thermometer is from 0°C to 130°C with 1C° graduations. This thermometer is also equipped with an auxillary needle which is magnetically attached to the temperature pointer and can be used to measure maximum and minimum temperature readings. The cost of the thermometer is $15.55.

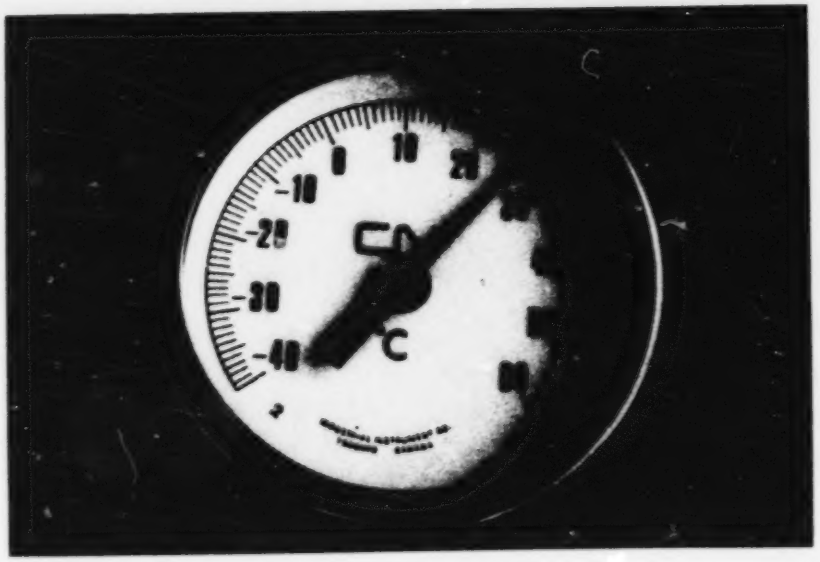


PTC Model
674-C
top view

PTC Model
674-C
bottom view
Note aggregate
caught in bi-
metal spring

B.2.2.5 Thermometer 5, Alexander Wig Industries, CN Track Thermometer

This thermometer is made by A. Wig Industries for Canadian National Railways Ltd. It is primarily used to measure track temperature. The thermometer, like the Pacific Transducer Model 309,is totally enclosed. The base picks up heat from the surface and in turn heats up the bi-metallic strip. As can be seen from the accompanying photograph, the base of this thermometer is very large. This results in a very stable temperature reading, however, it has the accompanying disadvantage of taking a long time to record the temperature (up to 20 minutes). The thermometer's dial has a diameter of 50 mm, the range is from - 40°C to 60°C with 1C° graduations. The thermometer costs under $30.00 (Mr. A. Wig notified the writer that he could manufacture surface thermometers custom made to MTC's specifications for under $30.00).



A. Wig - CN Track Thermometer
top view

Appendix C

Paving cessation criteria used by other agencies

A survey was carried out to determine what paving cessation criteria are used by other road agencies.

All the Canadian provinces, except Quebec, have paving cessation criteria based on air temperature. Quebec, has recently switched to statistically based specifications with penalties assessed to the contractor if the required densities are not met. The information relating to the Canadian Provinces was obtained in telephone conversations and is not necessarily complete.

Information relating to the American states was obtained from library copies of their respective specifications. Like Quebec a lot of the states have recently switched to statistically based specifications and the information listed is not necessarily up to date.

C.1 Canadian Provinces

PROVINCE	MINIMUM AIR TEMPERATURE	OTHER CRITERIA
Ontario	7°C - surface 2°C - binder, single course pavement	- dry surface - min. mix temp. prior to rolling
Alberta	4°C and rising	- dry and unfrozen - min. mix temp. to permit proper compaction - weather and temp. accept. to eng.
British Columbia	4°C and rising	- dry and unfrozen surface
Manitoba	6°C - surface 0°C - binder or base	- dry surface
New Brunswick	7°C - surface 0°C - binder	- after Oct. 15 pave only if weather is acceptable - start paving on May 15 or when weight restrictions on roads are lifted
Newfoundland	4°C and rising	
Quebec (Prior to intr.of ERS)	Base temp. of 4°C and rising	- dry surface free of mud - permission required from eng. to lay surface courses less then 50 mm high if the temp. is less than 7°C
Saskatchewan	2°C and rising	- dry and unfrozen surface

C.2 American States

C.2.1 States using paving cessation criteria based on air temperature

STATE	MINIMUM AIR TEMPERATURE	OTHER CRITERIA
Florida	4°C	- dry and frost free surface
Georgia	15°C	- dry and frost free - min. temp. of mix requirement depends on thickness of lift
Illinois	4°C - surface 0°C - binder	- dry surface - weather conditions suitable for paving
Indiana	4°C	- no paving Nov. 1 to April 1 - dry surface - weather conditions suitable for paving
Michigan	10°C - surface 4°C - binder	- no paving in upper peninsula Oct. 15 - June 1 - no paving in lower peninsula Nov. 1 - May 1 - dry surface
Oregon	4°C	- no paving during rain or under adverse weather conditions

C.2.2 States or other road agencies using paving cessation criteria based on base temperature

C.2.2.1 Federal Highway Administration Board (FHWA)

Paving is not permited under the following conditions: wet or frozen base, when the weather prevents the proper handling or finishing of the mixture and when the base temperature is less than specified in the table below.

Thickness of lift	Min. Temp. required for surface course	Min. Temp. required for binder or base course
<30 mm	13°C	13°C
30 - 60	7°C	2°C
60 -100	2°C	2°C
>100	-	-4°C

C.2.2.2 Iowa

Paving is not permitted when the base is wet, after November 1 (October 1 for surface courses less than 25 mm) or when the base temperature is less than specified below.

Thickness of lift	Min. Temp. required for surface course	Min. Temp. required for binder or base course
20 mm	16°C	4°C
25 mm	10°C	4°C
40 - 50 mm	7°C	4°C
50 - 80 mm	4°C	2°C
> 80 mm	-	-4°C

C.2.2.3. New York

Paving is not permitted when the base is wet, when the weather conditions prevent the proper handling and finishing of the mixture and when the base temperature is less than specified below.

Thickness of lift	Min. Temp. required for surface course	Min. Temp. required for binder or base course
≥ 25 mm	10°C	No Paving Oct 15 to May 1 in Northern New York and Nov. 15 to April 1 in Southern New York
25 mm - 80 mm	7°C	No Paving Oct 15 to May 1 in Northern New York and Nov. 15 to April 1 in Southern New York
> 80 mm	4°C	No Seasonal Restrictions

C.2.2.4 West Virginia

West Virginia permits paving from May 1 to November 1. Within this period paving is restricted to times when the weather conditions are satisfactory to the engineer and when the base temperature is 4°C or higher.

C.2.2.5 Washington

Paving is not permitted when the base is wet, when the weather conditions prevent the proper handling or finishing of the bituminous mixture or when the surface temperatures are less than specified below.

Thickness of lift	Min. Temp. required for surface course	Min. Temp. required for sub-surface courses
< 30 mm	13°C	13°C
30 - 60 mm	7°C	2°C
60 -105 mm	2°C	2°C
>105 mm	-	-4°C*
* only allowed when subgrade is dry, not frozen and air temperature is rising.		

C.2.3 States using a combination of air temperature and surface temperature or other criteria

C.2.3.1 Delaware

Paving is permitted when the surface is dry and only when the weather conditions are suitable. After September 30 loads are to be delivered in insulated trucks.

C.2.3.2 Massachusetts

The temperature of the mixture when delivered is governed by the following:

Air Temperature	Thin Lift (<75 mm)	Thick Lifts (>75 mm)
2°C	150°C	140°C
4°C	145°C	130°C
18°C	140°C	125°C
32°C	135°C	125°C

C.2.3.3 Minnesota

Paving is not permitted when the roadbed and weather are unfavourable and from Oct. 15 in the north and November 1 in the south until the removal of seasonal road restrictions.

C.2.3.4 Pennsylvania

No paving is to take place when the air temperature or the surface temperature is 4°C or lower. Also, no paving is to take place from Oct. 15-31 to April 1-15 unless approved by the engineer.

C.2.3.5 Virginia

Virginia's paving cessation criteria is based on the time available to properly compact the mat (the time required for the mix to cool to 80°C). For thin lift (<40 mm) a min base temperature of 16°C is required.